

A robust inverse approach for estimating the magnetic material properties of an electromagnetic device with minimum influence of the uncertainty in the geometrical parameters

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Abstract:

The magnetic properties of the core material of an electromagnetic device (EMD) can be characterized by solving an inverse problem, where sets of measurements are properly interpreted using a forward mathematical based model. However, the uncertainties of the geometrical parameters values in the forward model result in recovery errors in the reconstructed material parameters values. This paper proposes a novel inverse approach technique, in which the propagations of the uncertainties in the model are limited. The proposed methodology adapts the cost function that needs to be minimized with respect to the uncertain geometrical model parameters. We applied the methodology onto the identification of the magnetizing B - H curve of a switched reluctance motor core material. The numerical results show a significant reduction of the recovery errors in the identified magnetic material parameter values.

Introduction:

The magnetic material properties in electromagnetic devices (EMDs) are classically identified by means of the standard techniques, such as an Epstein frame or a single sheet tester. However, this requires extra samples of the electrical steel sheet of which the EMD is manufactured, which are mostly not available. Moreover, the magnetic material characteristic may be altered during the construction of the EMD. Therefore, it is convenient to characterize the magnetic properties on the specific geometry of the EMD itself.

Recently, a coupled experimental-numerical inverse approach is proposed for identifying the magnetic material properties in an EMD. This inverse approach iteratively minimizes the difference between the numerical model responses and the measurement quantities. However, numerical model responses are highly affected by the uncertainties in the geometrical model parameters values, especially the air gap thickness. Therefore, a more robust inverse approach is needed.

We present in this paper a novel inverse approach for estimating the magnetic material properties of an EMD, e.g. a switched reluctance motor, with minimum influence of the uncertainty in the geometrical model parameters values.

Studied geometry and material modelling:

Fig. 1-a shows the schematic diagram of the 6/4 SRM. The geometry is characterized by eight geometrical parameters: t_{sp} , t_{rp} , D_{ri} , D_{re} , D_g , D_{si} , D_{se} , g , where t_{sp} and t_{rp} are the stator and the rotor pole width, D_{ri} and D_{re} are the internal and external diameter of the rotor yoke, D_g is the diameter of air gap, D_{si} and D_{se} are the internal and external diameter of the stator yoke. g is the air gap thickness, which is assumed to be the most dominant uncertain parameter. The other seven parameters are assumed to be precisely known; $[t_{sp}, t_{rp}, D_{ri}, D_{re}, D_g, D_{si}, D_{se}] = [17, 20, 25, 44, 60, 109.2, 135] \text{ mm}$. The mean value of the uncertain g is 0.25 mm .

The normal magnetizing B - H curve of the SRM magnetic core material is characterized by

$$\frac{H}{H_0} = \frac{B}{B_0} \left(1 + \left(\frac{B}{B_0} \right)^{(\nu-1)} \right) \quad (1)$$

with parameters $\mathbf{u} = [H_0, B_0, \nu]$. The values of these parameters are unknown and need to be identified using an inverse approach.

Inverse problem formulation:

In order to identify the magnetic material parameters \mathbf{u} of the studied SRM, the inverse problem is formulated, in which the quadratic difference between the measured and simulated quantities is iteratively minimized. In this paper, we consider different measurement quantities; only inverse problem based on the static torque measurements is mentioned in this digest. The following objective function needs to be minimized:

$$OF(\mathbf{u}) = \sum_{k=1}^K \left\| T_s(\xi_k, \mathbf{g}, \mathbf{u}) - T_m(\xi_k) \right\|_{I=\cos \tan t}^2 \quad (2)$$

with $T_m(\xi_k)$ being the measured static torque for the k^{th} rotor angle position ξ_k , and $T_s(\xi_k, \mathbf{g}, \mathbf{u})$ being the simulated static torque value. K is the number of considered rotor positions. Here, $K=19$, i.e. $\xi = [0^\circ, 2.5^\circ, \dots, 45^\circ]$.

Proposed methodology:

The proposed methodology is mainly based on adapting, at each iteration step, the objective function that needs to be minimized with respect to the sensitivity of the model responses to the uncertain geometrical model parameters. In this application, this is the sensitivity of the torque to the air gap thickness value. In this method, which is called the minimum path of the uncertainty (MPU), the objective function mentioned in (2) is adapted as follows:

$$OF_{MPU}(\mathbf{u}) = \sum_{k=1}^K \left\| T_s(\xi_k, \mathbf{g}, \mathbf{u}) + \alpha \frac{dT_s(\xi_k, \mathbf{g}, \mathbf{u})}{dg} - T_m(\xi_k) \right\|_{I=\cos \tan t}^2 \quad (3)$$

where α is a constant and can be obtained by performing a linear fitting between the vector $\vec{T}_m(\xi) - \vec{T}_s(\xi, g, u)$ and vector $\frac{d\vec{T}_s(\xi, g, u)}{dg}$. The k^{th} element of these vectors is

defined as the value for angle ξ_k .

When minimizing the objective function (3), a path (parameter values u^j for j^{th} iteration) is followed that is minimally affected by the uncertainties. Indeed, a linear forward model, i.e. $T_s(\xi_k, g, u) + \alpha \frac{dT_s(\xi_k, g, u)}{dg}$, for $k=1, \dots, 19$, is used with incorporation of dependence to the uncertain parameter values and with estimate of uncertainty (α).

Results and Conclusion:

Fig. 1-b shows the recovery errors in the identified magnetic material properties of the SRM core material when using the traditional and proposed inverse approach. The recovery error values are calculated based on the deviation of the root mean squared values of the recovered B - H curves compared to the original B - H characteristics.

It is clear from Fig. 1-b that the recovery error is appreciably decreased compared to the traditional one, which confirms the effectiveness of the proposed methodology. The complete results including noise effect and experimental validation are presented in the full paper.

